The Absorption in Lead of the γ-Rays emitted by Radium B and Radium C.

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In a previous paper by Rutherford* and the author attention has been drawn to the fact that the two types of γ-radiation emitted by radium B and radium C which are exponentially absorbed by aluminium both show irregular absorption curves when lead is used as the absorbing material. The curve obtained for pure radium C was observed to fall far more rapidly than was to be expected from an exponential law of absorption, and was found to become exponential only after traversing a thickness of 1·5 cm. of lead. The absorption curve in lead of the γ-rays from radium B was obtained by taking the difference between the radium (B+C) and the radium C curves. The results so obtained were not determined with very great accuracy, but they served to show that in this case, too, the absorption is not exponential, and that the absorption coefficient rapidly diminished from about $\mu = 11\,(\text{cm.}^{-1})$ to $\mu = 2\,(\text{cm.}^{-1})$. The accuracy of the curves did not, however, permit of their complete analysis as in the case of those previously obtained for aluminium.

During the course of his work on characteristic radiations Barkla† has pointed out and investigated the anomalous effect on the absorption of a characteristic radiation by an element whose atomic weight is near to that of the element which emits the radiation. His experiments were, however, confined to elements of comparatively low atomic weight. As the atomic weights of radium B and radium C can only differ by a small amount, and as they have atomic numbers‡ differing only by unity, viz., radium B = 82 and radium C = 83, it seemed of importance to determine accurately the absorption curves in lead, and to examine whether any additional information can be obtained which may indicate whether the radiations emitted by radium B and radium C are characteristic of these elements and fall into the series given by Barkla.

Method of Experiment.—It has been pointed out that the absorption curve for the radium B radiation was previously obtained as a difference curve by

* Rutherford and Richardson, 'Phil. Mag.,' vol. 25, p. 722 (1913).

† Barkla, 'Phil. Mag.,' vol. 22, p. 396 (1911).

‡ Rutherford and Andrade, 'Phil. Mag.,' vol. 27, p. 854 (1914).

finding first of all the curve using an α-ray tube as the active source, and by allowing for the effect due to the radium C. In order to obtain direct results it was thought better if possible to determine the curve using radium B itself as the source. This is rather difficult owing to the rapid transformation of radium B into radium C. The ideal arrangement was therefore to obtain a source of pure radium B, and then to find several points on the absorption curve whilst the percentage of radium C present was small. In order to do this it was necessary to have a source of pure radium B. This was obtained in the following manner: 200 millicuries of radium emanation were enclosed in a glass tube over mercury as shown in fig. 1. The whole was then allowed to remain for a period greater than four hours so that radioactive equilibrium was established. The emanation was then pumped off, and the glass tube was washed with absolute alcohol in order to remove all traces of grease and emanation. By this method one obtains on the glass a deposit of radium A, radium B, and radium C in equilibrium. In order to remove the radium C some nickel filings were placed in the tube, which was then filled with boiling dilute hydrochloric acid. The acid was then kept boiling for about 15 minutes. Experiment* had previously shown that in such a case the radium C is deposited on the nickel, and that the separation is very efficient. It was hoped that by this means the whole of the radium C would be completely removed. Moreover, since the nickel was kept in the solution for 15 minutes the whole of the radium A had in that time become transformed into radium B, and consequently only pure radium B should remain in solution in the acid. The solution was then quickly poured off on to a quartz plate and evaporated to dryness. The time at which the acid was poured off was noted and in the calculations it was assumed that at that moment only pure radium B existed in the solution. In order to determine how far the assumption was accurate it was only necessary to measure the growth of the radium C by measuring the rise of activity in the ordinary way through a thickness of 1·5 cm. of lead. This can then be compared with the theoretical rise curve as deduced from the theory of successive changes, by assuming the matter to be initially pure radium B. The results of several experiments showed a perfect agreement between the theoretical and actual rise curves and thus justified the assumption that the removal of the radium C by the nickel was quite complete.

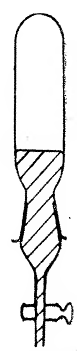


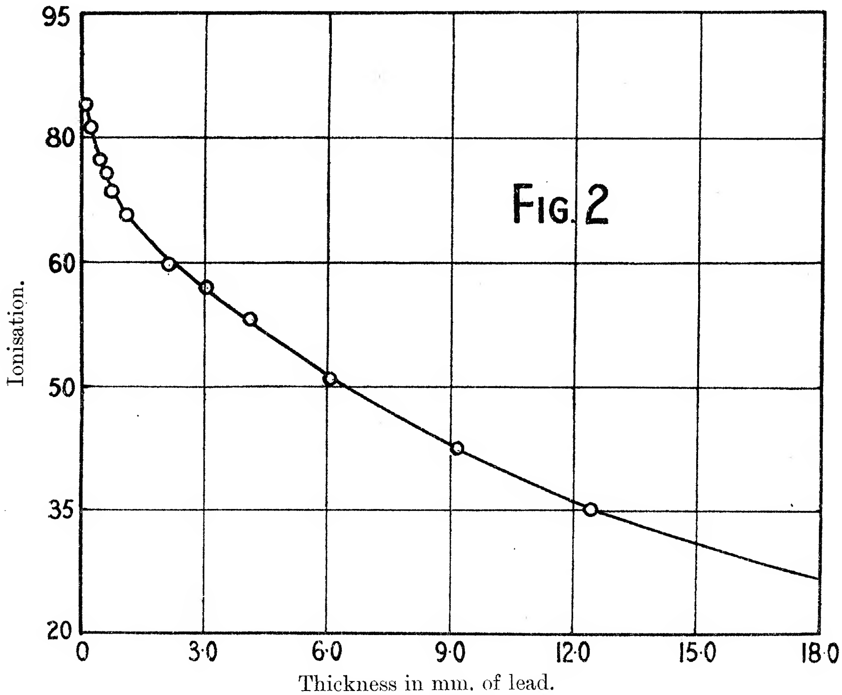
Fig. 1.

In order to determine the absorption curves the apparatus and method already adopted and described in a previous paper† was used.

* Rutherford and Richardson, 'Phil. Mag.,' vol. 25, p. 722 (1913).

† Rutherford and Richardson, 'Phil. Mag.,' vol. 26, p. 324 (1913).

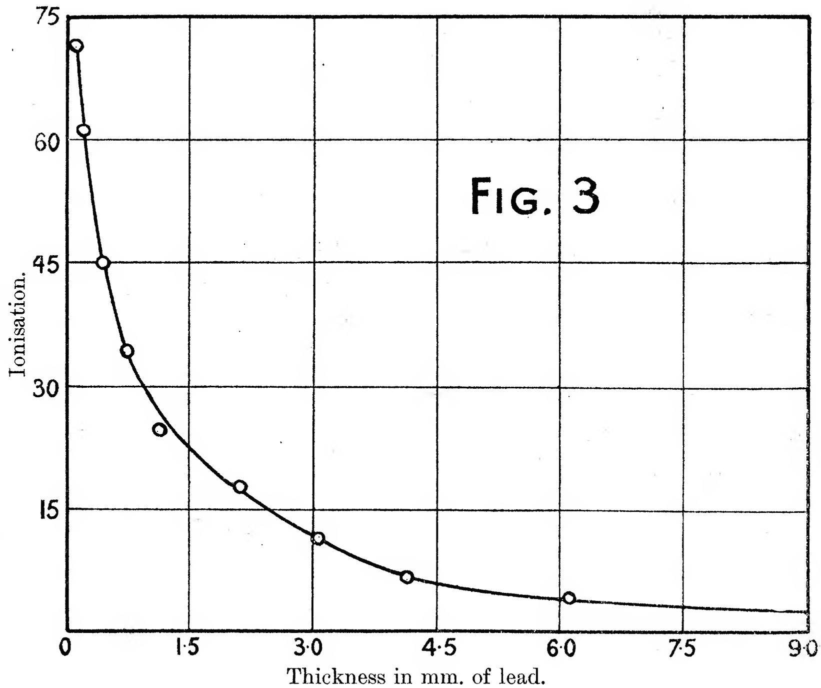
The absorption curve in lead for the radium C radiation was, first of all, carefully determined. For this experiment a source of pure radium C on a nickel wire was used, the soft radiation excited in the nickel being cut out by a very thin sheet of lead. The curve was obtained up to a thickness of 1·8 cm. of lead, after which point the absorption was found to be exponential with an absorption coefficient $\mu = 0{\cdot}5\,(\mathrm{cm.}^{-1})$, the value already obtained in previous experiments.* The curve, fig. 2, shows the results obtained.



The radium B absorption curve was next obtained by using the deposit of radium B prepared in the manner already indicated. This curve was, of course, difficult to determine owing to the variation of the amount of radium C present from moment to moment, and also owing to the rapid decay of the radium B itself. The actual curve was obtained in the following manner. The total ionisation was measured for the various thicknesses of lead foil required, in the usual manner. During the course of the experiments several readings were taken of the ionisation through a thickness of 2 cm. of lead, that is, a thickness sufficiently great to cut out entirely the effect due to the radium B. By this means it was possible to calculate the effect due to the radium C present at any time during the experiment, and hence, from fig. 2,

* Rutherford and Richardson, 'Phil. Mag.,' vol. 25, p. 722 (1913).

the effect corresponding to the particular thickness of the absorber being used. The difference between this and the observed ionisation gives the true effect due to the radium B alone. All that is then necessary is to correct the readings for the decay of the radium B itself. In this manner the absorption curve shown in fig. 3 was obtained. This experiment was



repeated several times, the agreement between the separate experiments being very good.

In order to examine whether the absorption curve for the radium B radiation could be accurately obtained by using an α-ray tube as source and allowing for the effect of the radium C, the curve was also again carefully determined. The following Table, which gives the results actually obtained by the two methods, shows that the agreement is well within the limits of experimental error.

Analysis of the Radium B Absorption Curve.—The curves obtained were analysed in the manner already described in previous papers (*loc. cit.*). The results showed that the radium B radiation consists of three types which are exponentially absorbed. The hardest type has an absorption coefficient $\mu = 1{\cdot}5$ (cm.$^{-1}$). The ionisation (measured with an electroscope filled with methyl iodide vapour) due to this type comprises about 12 per cent. of the

Table I.—Absorption in Lead of the γ-Rays of Radium B.

Thickness of lead.	Radium B as source.	α-ray tube as source.
mm.		
0·1	100	100
0·2	85·7	82·0
0·4	63·1	62·7
0·7	47·9	47·1
1·09	34·4	35·4
2·13	26·2	22·8
3·06	16·5	16·3
4·15	9·0	10·8
6·12	6·2	6·2
9·18	3·5	3·6

total ionisation under the experimental conditions. The two remaining types have coefficients $\mu = 6·0$ (cm.$^{-1}$) and $\mu = 46$ (cm.$^{-1}$). About 26 per cent. of the total ionisation is due to the former type of radiation and 62 per cent. to the latter.

Examination of the Radium C Absorption Curve.—Attention has already been drawn to the fact that the absorption curve for the radium C γ-radiation is not exponential from the beginning, but no analysis had so far been attempted. The analysis, performed as in the previous cases, of the curves obtained showed that, under the experimental conditions, about 85 per cent. of the total ionisation produced by radium C is due to the very penetrating type for which $\mu = 0·5$ (cm.$^{-1}$). The absorption curve of the remaining 15 per cent. of the radiation seemed to be very similar in character to that obtained for radium B. The respective curves are shown in fig. 4.

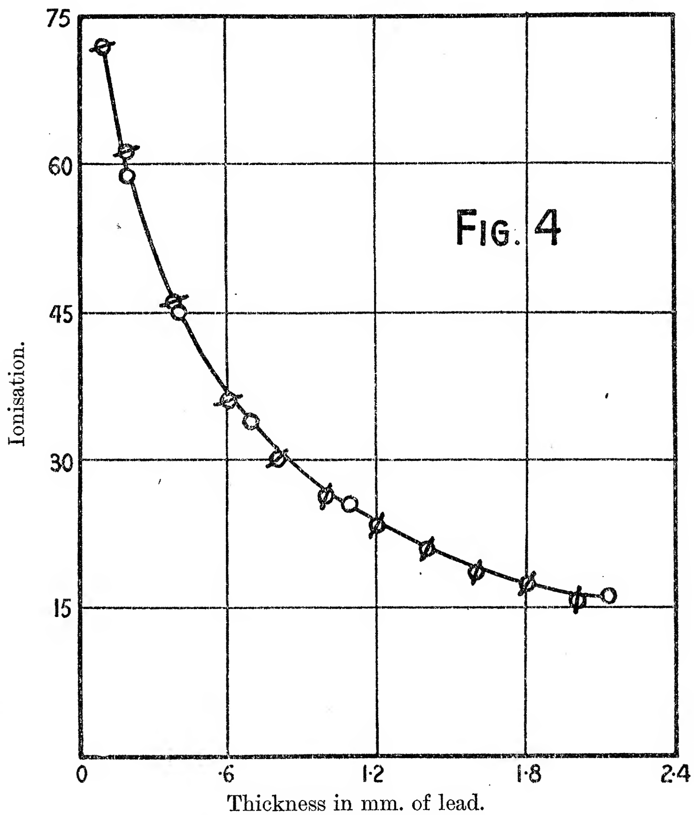
The agreement is well within the errors of experiment and gives conclusive evidence that these radiations are indistinguishable by absorption methods.

Discussion of the Results.—The examination of the absorption curves in lead thus shows that radium B and radium C both emit three types of radiation which are exponentially absorbed, in addition to the very penetrating type of radiation emitted by the latter body. These results are quite in agreement with those recently obtained by Rutherford and Andrade* in their determination of the spectrum of the penetrating γ-rays from radium B and radium C. They concluded that some of the lines in the spectrum were probably close doubles, the lines being considerably wider than would be the case for a radiation of single frequency. The results thus appeared to indicate that part of the spectrum of radium B is not very different from that of radium C. Of course such a small difference of frequency in the radiations as

* Rutherford and Andrade, 'Phil. Mag.,' vol. 28, p. 264 (1914).

indicated by the above experiments would be difficult to detect by the ordinary absorption methods.

It will be observed that the radiations emitted by radium B evidently correspond to that which was previously thought to consist of one single type



○ Radium B—absorption curve in lead ; ϕ Radium C—absorption curve in lead (soft type only).

and for which $\mu = 0{\cdot}51$ (cm.$^{-1}$) in aluminium. Moreover, from the results given previously (*loc. cit.*), it was assumed that the radiation from radium C consisted of the very penetrating type only, which has the absorption coefficient $\mu = 0{\cdot}115$ (cm.$^{-1}$) in aluminium. It was, however, pointed out that the presence of a few per cent. of the $\mu = 0{\cdot}51$ type of radiation mixed with the more penetrating type would be very difficult to detect. Owing, however, to the much more rapid absorption of this particular radiation by lead it is easy to demonstrate that it actually does exist.

It should be observed that none of the radiations whose absorption in lead

has been investigated correspond with that emitted by radium B* and radium C† and for which $\mu = 40$ (cm.$^{-1}$) in aluminium. The latter radiation would probably have an absorption coefficient of the order 1000, in lead, and hence would be entirely cut out by the thinnest absorbing layers used in these experiments. The examination of the absorption in lead of this radiation has not yet been completed on account of the impossibility of obtaining absorbing layers of lead sufficiently uniform and thin.

Characteristic Radiations of Radium B and Radium C.—Evidence has already been given by Rutherford‡ which indicated that the penetrating radiation emitted by radium C might be the K series characteristic radiation of this element. The more recent results of Rutherford and Andrade have, however, led them to conclude that the γ-radiation from radium B is the K series characteristic of this element, whilst the very penetrating radium C radiation belongs to some higher series not before observed. It seemed of importance therefore to examine the absorption of these radiations by elements of atomic weight very nearly the same as that of radium C in order to find whether any anomaly in the absorption occurs such as was previously found by Barkla for the elements of low atomic weight. It will be remembered that the absorption coefficient of the radiation characteristic of an element is abnormally high for an absorber of atomic number slightly less than that of the element emitting the radiation. It would appear therefore that if the very penetrating radiation emitted by radium C is the K series characteristic of this element then it should be more readily absorbed in mercury or gold than in lead. It was not found practicable to determine complete absorption curves in the elements of high atomic weight, owing to the difficulty of obtaining large thicknesses of these materials, but comparative values of the absorption coefficients have been determined under the same conditions of experiment. Care was of course taken in every case to cut out all the radium B radiation by inserting a suitable thickness of lead. The results obtained are given in the following Table.

Table II.

Absorber.	Atomic number.	μ/d.
Uranium	92	0·0475
Lead	82	0·0435
Mercury	80	0·0416
Gold	79	0·0426
Barium	56	0·0371

* Rutherford and Richardson, 'Phil. Mag.,' vol. 25, p. 722 (1913).
† Richardson, 'Roy. Soc. Proc.,' A, vol. 90 (1914).
‡ Rutherford, 'Phil. Mag.,' vol. 24, p. 453 (1912).

It will be seen that no decided change in the absorption coefficient can be detected for the absorbers of different atomic number.

The examination of the absorption curves for the radiation emitted by radium B was then undertaken, the elements uranium, lead, and mercury being taken as absorbers. The absorbing sheets had to be in the form of very thin layers of the oxides, and hence the curves could not be obtained with very great accuracy. Moreover, the actual curves could not be analysed owing to the impossibility, under the experimental conditions, of finding the complete curve for each absorber. The results actually obtained are compared in the following Table:—

Table III.

Weight per unit area of lead oxide.	Ionisation.	Weight per unit area of uranium oxide.	Ionisation.	Weight per unit area of lead.	Ionisation.	Weight per unit area of mercuric oxide.	Ionisation.
grm.		grm.		grm.		grm.	
0·238	100	0·233	100	0·227	100	0·226	100
0·461	89·7	0·453	87·2	0·454	87·5	0·448	87·8
0·790	78·9	0·785	75·0	0·794	76·0	0·806	73·7
1·237	72·5	1·239	69·4	1·236	70·9	1·262	69·4
1·689	68·6	1·705	65·9	1·690	62·4	1·700	62·0
2·411	63·8	2·404	62·6	2·415	58·6	2·962	51·4
4·100	54·4	4·109	51·9				
5·337	49·5	5·348	47·0				
6·127	46·7	6·133	43·9				
6·588	44·6	6·586	42·6				

It will be seen from these results that the curves obtained are almost identical, and hence it seems certain that in the case of the radium B radiation, too, no rapid change in the value of the absorption coefficient takes place. If the radiations emitted by radium B and radium C are characteristic of these elements then it would appear that the characteristic radiations of the elements of high atomic weight do not behave as regards absorption in quite the same way as those emitted by elements of lower atomic weight. The direct excitation of the characteristic radiations of the elements of high atomic weight has not, so far, been obtained. If this could be undertaken and the absorption of the radiations then examined the results should give much information on this subject.

Summary.

1. The absorption curves in lead of the radiations emitted by radium B and radium C have been determined and analysed.

2. In addition to the penetrating type of radiation for which $\mu = 0{\cdot}5$ (cm.$^{-1}$)

in lead, radium C has been found to emit soft types for which $\mu = 46$, $\mu = 6{\cdot}0$, and $\mu = 1{\cdot}5$, and which are practically absorbed by 1·5 cm. of lead.

3. The analysis of the radium B absorption curve shows that in addition to the radiation $\mu = 40$ in aluminium, the rays emitted consist of three types for which $\mu = 46$, $\mu = 6{\cdot}0$, and $\mu = 1{\cdot}5$ for lead. The close similarity of this latter radiation with that of the soft portion emitted by radium C, already observed by Rutherford and Andrade, has been established.

4. The absorption of the radiations in different elements has been examined and the bearing of the results discussed. No evidence of anomalous absorption has been found in the case of the penetrating radiations.

I have much pleasure in thanking Sir E. Rutherford for the constant help and valuable advice which he has given me throughout the course of these experiments.